A contribution towards a methodology for managing learning, multi-skilling and performance on the shop floor

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Abstract: High-performance work is applied in production methodologies like lean production. In this approach, workers are able to perform several different tasks and participate in continuous improvement. In order to be able to do this, workers must obtain practical knowledge of the tasks and acquire a global vision of the process. Work plans must take into account workers' performance when they begin working on new tasks, the cost of learning new tasks in terms of training or low performance, the effects of previous knowledge and personal absorption capacity, and a final knowledge objective. We propose a task-assignment model that takes these factors into account. A particular version of the model is defined in detail. Several instances based in a real case are solved using optimization software. This proves that the model is affordable for moderate-sized problems. The information that can be obtained using this method is presented. These results form the basis for an applicable methodology to be developed in future research.

Keywords: absorption capacity, high-performance work, multi-skilling, work planning.

Categories: G1.6, J.4

1 Introduction

In successful industrial companies, the functions of factory workers are becoming increasingly broad. Workers perform several tasks and participate in continuous improvement. Ideally, workers are able to perform all of the tasks assigned to their team and several others. Work becomes far from mechanical. Good management of task assignment and knowledge is necessary. Many factors must be considered, including absorption capacity and experience. This paper is a first step toward developing a methodology that meets these requirements. Although the model has not been yet applied, the first results are promising. The proposed model is shown to be useful under certain circumstances and its possibilities are presented.

This paper is organized as follows. Section 2 describes the basis and characteristics of the general model. Section 3 defines a particular case of the general model. The model is formulated and several instances are solved with optimization software. The results of these instances are shown and the information that can be obtained using the model is presented. The paper ends with conclusions, suggested future work and references.

2 Task-assignment and learning model: general case

Workers' knowledge is critical in factories that use work teams, multi-skilling, improvement meetings and empowerment. High-performance work practices are applied by lean production [Jones 92], agile manufacturing (see [Kidd 94]: p. 122) and any application of Total Quality principles [Duguay 97]. In order to participate effectively in improvement meetings and assume empowered tasks, workers need a vision beyond a specific task. At the very least, this vision must include work-process knowledge, which is defined as experience and knowledge about interactions and possible optimizations in the work process [Scheib 05].

The way in which knowledge is generated and disseminated clearly sets high-performance work apart from traditional work. In traditional factories, knowledge has a unique origin and direction. Knowledge holders (workers and standards) do not interact. Workers have a mechanical role. In high-performance work, workers are active agents of knowledge. If teams are self-directed, how the work is done depends on the task requirements and the methods adopted by the team. In lean factories, methods are strictly established by standards. Even physical labourers need knowledge to determine and apply standards. Workers and standards interact in quality circles and rotation. In quality circles standards and their application are discussed by the workers. Rotation gives them direct knowledge about the standards and their application. [Fig. 1] shows the differences between traditional and lean work. In lean we use "competences" instead of "skills" because knowledge is deeper.

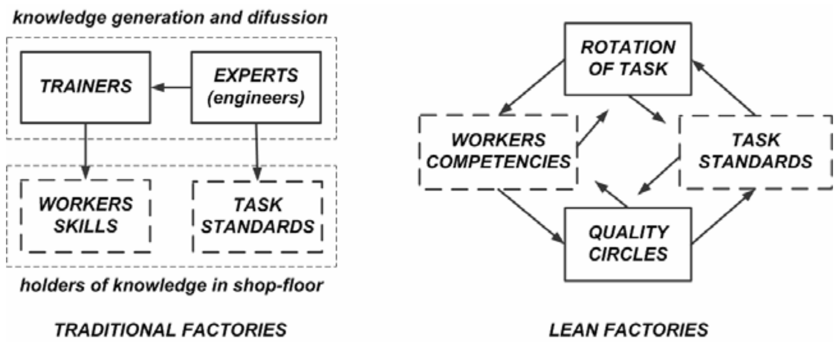

Figure 1: Knowledge generation and diffusion in traditional and lean factories.

Rotation is necessary for this entire schema. Rotation provides workers with a general vision, enriches quality circles, tests standards, and usually makes standards more straightforward because different people are involved. Rotation implies the need to learn multiple tasks. Multi-skilling is therefore a condition of rotation. Moreover, multi-skilling is easer with rotation because different skills are put into practice. Rotation and multi-skilling also imply costs, because workers must be trained and their performance decreases when they start working on a new task.

Task rotation has a great influence on work planning. With static assignments, training is only necessary for new hires or when an assignment is changed. Workers usually do not change positions for years. With rotation in a dynamic environment, learning a new task becomes a regular activity. [Fig. 2] shows a general schema for planning in this case. Planning for a period requires data about the regular work time of the staff, the expected workload and the workers' knowledge (i.e. the ability to perform different tasks). Workers assume tasks they were not previously familiar with. This implies a cost of training and low performance. This cost also depends on absorption capacity (determined by the task, the knowledge of workers of similar tasks and personal capacity).

Task assignment has been discussed in the literature. [Ernst 04] found 32 studies on scheduling published until 2003 that included task assignment. Some of the studies took knowledge and learning aspects into account in task assignment. One such study concludes that global performance estimation is considerably better with individual rates of learning and forgetting than with a uniform rate [Shafer 01]. Another study assigned tasks in a way that minimized training cost, which was assumed to be a monetary cost [Slomp 05].

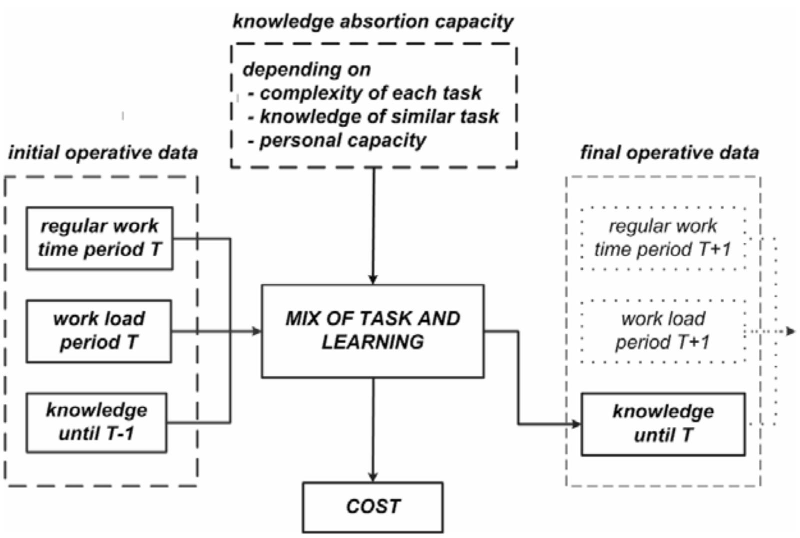

Figure 2: Task-assignment and learning model.

To assign tasks in a multi-skilling team, we have developed a model based on the schema defined above and illustrated in [Fig. 2]. The model has the following characteristics: (1) any worker can be assigned to any task; (2) considers cost of learning, based on training, learning-by-doing or both; (3) the absorption capacity is evaluated in each situation; and (4) there is a knowledge (multi-skilling) objective for the end of the planning horizon. The next section details a specific model that applies these ideas.

3 Task-assignment and learning model: a learning-by-doing case

3.1 Description

Let us establish how knowledge and learning aspects will be included in the planning model. A complete model would require learning functions that can obtain each worker's performance according to its characteristics and experience and forecast training time and cost. Here we have used a case that is simpler but complete enough to demonstrate the basic characteristics of the model. Workers need some experience with a task in order to have a regular performance. Until then, performance is constant and depends on the task, experience with other tasks, and personal capacity. A knowledge objective is included. Learning is exclusively based on learning-by-doing. Cost is reflected by the overtime required to cover the workload and the other conditions and generates the objective function.

The model assumes that each block of regular time or overtime is assigned entirely to a single task. This condition is not formally restrictive because the blocks can be as small as necessary, but with small blocks this method is numerically unaffordable. The block structure was maintained because it makes the results easier to understand and the possibilities of the model more visible. In real applications, a non-integer model must be used.

The original elements of this model are performance until experience is gained and the knowledge objective. They have been defined using the following factors:

1. Performance of workers without experience in a task.
- Number of time units of experience (threshold) needed to obtain regular performance in each task.
- Each worker's initial experience with each task or experience necessary to obtain regular performance (whichever is lower). For example, if 10 days' experience is required and the worker has 20, only 10 are counted.
- A non-experienced worker's expected performance in each task, assuming he has no experience with other tasks and no special qualities ("non-experienced" means that he has not worked the number of time units required to obtain regular performance).
- A non-experienced worker's additional performance in a task due to his experience in other tasks.
- Each non-experienced worker's additional performance in a task due to his personal qualities.

2. Experience objective.
- Experience objective of the group working on task *j* calculated as the average of the individual proportions of the experience required to obtain regular performance (for example, if the objective is 0.75 and experience required to obtain regular performance is 20 days, a worker with full experience – 20 days or more, counting 20 days – and another with 10 days' experience will cover the objective).

3.2 Formulation

A mixed-integer linear program (MILP) assigns standard work-time schedules and overtime when necessary. Workload is covered. Performance depends on experience and personal capacity. Final experience must be reached. Overtime is minimized.

Data:

W	Set of workers.
n	Number of workers (cardinal of W).
J	Set of types of tasks.
T	Number of periods in the planning horizon.
U	Number of time units of regular work in each period.
mo	Length of possible overtime for each unit of regular time, in time units.
p_j	Experience time units required to obtain regular performance in task j ($j \in J$).
e_{ij}	Initial experience time units of worker i performing tasks j, or experience required for regular performance, whichever is lower (for all $j \in J$, $i \in W$).
$f_{1,j}$	Expected performance in a task j of a worker without experience in this task or any other task and with no special qualities (for all $j \in J$).
$f_{2,j}(s)$	Additional performance in a task j of a worker without experience in this task due to his experience in the other task, where s vector of situations of experience or non experience in the other task (for all $j \in J$).
$f_{3,i}$	Additional performance in a task of a worker i without experience in this task due to his personal capacity (for all $i \in W$).
l_{jt}	Workload for tasks of type j in period t (for all $j \in J$, $t=1 \ldots T$).
v_j	Experience objective of the group in task j (average) (for all $j \in J$).

Variables:

r_{utij}, o_{utij}, re_{utij}, ro_{utij} (for all $u=1 \ldots U$, $t=1 \ldots T$, $i \in W$, $j \in J$), binary variables indicating whether in time unit u of the period t worker i does task j with experience in regular time (re) or overtime (oe) or without experience in regular time (ru) or overtime (ou).

Model:

$$[MIN] \quad z = \sum_{(u=1,..,U;t=1,..,T;\forall i \in W;\forall j \in J)} (oe_{utij} + ou_{utij}) \tag{1}$$

Conditioned to

$$\sum_{(\forall j \in J)} (re_{utij} + ru_{utij}) \leq 1 \qquad (\forall u = 1,..,U; \forall t = 1,..,T; \forall i \in W) \tag{2}$$

$$\sum_{(\forall j \in J)} (oe_{utij} + ou_{utij}) \leq 1 \qquad (u = 1,..,U; t = 1,..,T; \forall i \in W) \tag{3}$$

$$e_{ij} + \sum_{(u=1,..,U;t=1,..,T)} (ru_{tij} + ou_{tij} mo) \leq p_j \qquad (\forall i \in W; \forall j \in J) \tag{4}$$

$$e_{ij} + \left[\sum_{(u'=1,..,u-1;t'=1,..,t-1)} (ru_{utij} + ou_{utij} mo) \right] + (re_{utij} + oe_{utij} mo) \geq p_j \qquad (\forall i \in W; \forall j \in J) \tag{5}$$

$$\sum_{(u=1,..,U,\forall i\in W)} (re_{utij}+oe_{utij}mo)+\sum_{(u=1,..,U,\forall i\in W)}(ru_{utij}+ou_{utij}mo)\cdot$$
$$\cdot(f_{1,j}+f_{2,j}(s)+f_{3,i})=l_{jt} \qquad (t=1,..,T;\forall j\in J) \tag{6}$$
$$\sum_{(\forall i\in W)}\left(e_{ij}+\sum_{(u=1,..,U;t=1,..,T)}(ru_{utij}+ou_{utij}mo)\right)\Bigg/ n \quad \ge \quad v_j \qquad (\forall j\in J) \tag{7}$$

Where: (1) objective function, (2) to avoid assigning more regular time than available, (3) to avoid assigning more overtime than possible, (4) non-experienced work only until threshold, (5) experienced work only after threshold, (6) workload coverage (vector s effect is converted to linear constraints by splitting variables r, s according to previous experience, details are not included for space reasons), (7) final experience.

3.3 Example

The example was obtained by adapting a real case. [Tab. 1] first shows the size of the example: 3 workers, 3 tasks, 2 periods of 5 time units (two weeks with five workdays) and a supplementary half day of possible overtime each workday. Second shows also the experience required to reach regular performance (e.g. task 1 is performed regularly after 5 days). The workload of each period is measured in time units. Total workload is equal to the total available work time. With regular performance by all workers for all tasks, no overtime would be necessary. Otherwise, the performance is lower and the overtime indicates the consequences of the lack of experience (which here measures knowledge). Third block shows performance in a task without the minimum experience, based on the worker’s experience in other tasks. This data is common to the different instances that will be solved.

<table>
<tr><td colspan="9">Size constants</td></tr>
<tr><td colspan="8">Number of workers</td><td>3</td></tr>
<tr><td colspan="8">Sets of types of tasks</td><td>3</td></tr>
<tr><td colspan="8">Number of periods in the planning horizon</td><td>2</td></tr>
<tr><td colspan="8">Number of time units of regular work in each period</td><td>5</td></tr>
<tr><td colspan="8">Length of possible overtime for each unit of regular time in percentage of time units</td><td>0.5</td></tr>
<tr><td colspan="9">Experience required to obtain regular performance and workload</td></tr>
<tr><td colspan="5"></td><td>Task 1</td><td>Task 2</td><td>Task 3</td><td>Total</td></tr>
<tr><td colspan="5">Time units of experience required to obtain regular performance</td><td>5</td><td>4</td><td>5</td><td></td></tr>
<tr><td colspan="5">Workload in period 1</td><td>7</td><td>4</td><td>4</td><td>15</td></tr>
<tr><td colspan="5">Workload in period 2</td><td>6</td><td>5</td><td>4</td><td>15</td></tr>
<tr><td colspan="9">Performance without experience based on experience with other tasks</td></tr>
<tr><td colspan="3">Performing task 1 with</td><td colspan="3">Performing task 2 with</td><td colspan="3">Performing task 3 with</td></tr>
<tr><td>Task 1</td><td>Task 2</td><td>Perfor.</td><td>Task 1</td><td>Task 3</td><td>Perfor.</td><td>Task 1</td><td>Task 2</td><td>Perfor.</td></tr>
<tr><td>0</td><td>0</td><td>0.3</td><td>0</td><td>0</td><td>0.2</td><td>0</td><td>0</td><td>0.6</td></tr>
<tr><td>0</td><td>1</td><td>0.3</td><td>0</td><td>1</td><td>0.5</td><td>0</td><td>1</td><td>0.6</td></tr>
<tr><td>1</td><td>0</td><td>0.3</td><td>1</td><td>0</td><td>0.2</td><td>1</td><td>0</td><td>0.6</td></tr>
<tr><td>1</td><td>1</td><td>0.3</td><td>1</td><td>1</td><td>0.5</td><td>1</td><td>1</td><td>0.7</td></tr>
</table>

Table 1. Initial data.

Next, four cases are presented and solved. The cases involve different experience, personal absorption capacities and final knowledge objectives. If all workers were experienced in all tasks, no calculation would be necessary and overtime would be zero. The cases are solved with the optimization software CPLEX 9.0, a Pc with Intel processor 2.8 MHz. and times of process around 10 to 120 minutes. [Tab. 2] shows the data. With experience 0 for all workers and tasks and no final knowledge objective, overtime must be 21 (Case 1). By comparing this result with the results of the other cases, the model's sensitivity to conditions can be seen. If one of the workers is fully experienced, overtime becomes 11 (Case 2). With the same conditions as Case 1 except the objective of full final experience, overtime increases to 25 (Case 3). Finally, an increase of 0.1 in non-experienced work due to the capacity of the workers gives an overtime of 18. The second block of [Tab. 2] shows the detailed work plan of the optimal solution for Case 1 in order to illustrate how the model runs.

Case data:		**Case 1**			**Case 2**			**Case 3**			**Case 4**		
		Task 1	Task 2	Task 3	Task 1	Task 2	Task 3	Task 1	Task 2	Task 3	Task 1	Task 2	Task 3
(1)	w1	0	0	0	5	4	5	0	0	0	0	0	0
	w1	0	0	0	0	0	0	0	0	0	0	0	0
	w1	0	0	0	0	0	0	0	0	0	0	0	0
(2)		0	0	0	0	0	0	1	1	1	0	0	0
(3)		0	0	0	0	0	0	0	0	0	0.1	0.1	0.1
Solution: (4)		21			11			25			18		

(1) Initial experience of each worker. (2) Experience objective. (3) Extra performance in non-experienced work due to personal qualities. (4) Overtime in the optimal solution of each case.

Case 1: detailed solution

		Worker 1					Worker 2					Worker 3					All							
(P)	(T)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(6)	(4)	(5)	(7)	(8)
1	1	0	1	8	1	0	0	0	0	0	0	0	2	6	3	0	3	14	3	14	4	0	7	7
	2	0	0	0	0	0	0	3	2	2	0	0	0	0	0	0	3	2	2	3	2	0	4	4
	3	0	3	4	0	1	0	0	0	0	0	0	0	0	0	0	3	4	3,5	3,5	0	1	4	4
2	1	5	0	0	1	0	0	0	0	0	0	5	0	0	5	0	0	0	0	0	6	0	6	6
	2	0	0	0	0	0	4	0	0	5	0	0	0	0	0	0	0	0	0	0	5	0	5	5
	3	5	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	4

(P) Period. (T) Task. (1) Experience of the worker at the beginning of the period. (2) Regular work without experience. (3) Overtime without experience. (4) Regular work with experience. (5) Overtime with experience. (6) Cost of non-experience (underperformance). (7) Work done. (8) Workload.

Table 2. Case data and solution.

4 Conclusions

Rotation is essential for high-performance work and in particular for lean production. As a result, learning must be taken into account and knowledge objectives (multi-skilling levels) must be established in planning task assignments. For the model to be realistic, absorption capacity must be related to experience in different tasks and personal capacity. We developed a model that only considers learning-by-doing and assumes that regular performance is obtained after a period of experience. The model was solved with data of a realistic example, which proved that can be solvable for moderate-sized cases and illustrated the information that this schema can offer.

5 Future work

This paper is a step toward obtaining a methodology to manage learning, multi-skilling and performance on the shop floor. To attain this objective, the following work is suggested: (1) Define the model with non-integer variables in order to solve cases of any size. (2) Analyse the incorporation of tested learning curves in the model. (3) Carry out numerical experiences with the new model. (4) Define the information requirements of a real application. (5) Apply the model to real cases.

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References

[Duguay 97] C. Duguay, S. Landry, & F. Pasin, From mass production to flexible/agile production, International Journal of Operations & Production Management, 17(12): 1997, 1183-1195.

[Ernst 04] A. T. Ernst, H. Jiang, M. Krishnamoorthy, B. Owens, & D. Sier, An annotated bibliography of personnel scheduling and rostering, Annals of Operations Research, 127(1-4): 2004, 21-144.

[Jones 92] D. Jones. Beyond the Toyota production system: the era of lean production. In C. Voss (Ed.), Manufacturing Strategy. Process and Content: 189-210. London: Chapman & Hall.

[Kidd 94] P. T. Kidd. 1994. Agile Manufacturing – Forging New Frontiers. Reading, MA: Addison-Wesley.

[Scheib 05] T. Scheib. Work Process Knowledge. In G. Zülch & H. Jagdev & P. Stock (Eds.), Integrating Human Aspects in Production Management: IFIP TC5/WG5.7. Proceedings of the International Conference on Human Aspects in Production Management. New York: Kluwer Academic Publishers.

[Shafer 01] S. M. Shafer, D. A. Nembhard, & M. V. Uzumeri, The effects of worker learning, forgetting, and heterogeneity on assembly line productivity, Management Science, 47(12): 2001, 1639-1653.

[Slomp 05] J. Slomp, J. A. C. Bokhorst, & E. Molleman, Cross-training in a cellular manufacturing environment, Computers & Industrial Engineering, 48(3): 2005, 609-624.